

A CNN-LSTM Based Model for EEG-Based Biometric Authentication

Rajesh Rajaan, Mani Butwall, Loveleen Kumar

Assistant Professor, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, Rajasthan, India

Received: 09 Dec 2025,

Received in revised form: 09 Jan 2026,

Accepted: 15 Jan 2026,

Available online: 20 Jan 2026

©2026 The Author(s). Published by AI

Publication. This is an open-access article under the CC BY license

(<https://creativecommons.org/licenses/by/4.0/>).

Keywords— Deep learning, biometric authentication, EEG, brain signals, and user identification

Abstract— Biometric authentication using Electroencephalogram (EEG) signals is a promising method for secure and unique user identification due to the inherent complexity of brain signals and their variability among individuals. This study introduces a deep learning approach for EEG-based biometric authentication. The proposed method attains elevated classification accuracy by employing Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) models on time-series EEG data. We analyze the performance using publicly available datasets such as the PhysioNet EEG Motor Movement/Imagery Dataset and DEAP. The results demonstrate superior accuracy and robustness in comparison to traditional machine learning models. We also did a thorough analysis of 20 related studies to put our work in the context of the present.

I. INTRODUCTION

The rapid proliferation of digital systems has significantly increased the demand for secure and reliable authentication mechanisms. Conventional methods such as passwords, PINs, and hardware tokens suffer from limitations including vulnerability to theft, brute-force attacks, and usability concerns. To address these shortcomings, biometric modalities such as fingerprint recognition, iris scanning, and facial recognition have been widely adopted. Although these approaches offer improved convenience, they remain susceptible to spoofing attacks and replication, thereby raising concerns regarding their robustness in high-security applications.

Electroencephalography (EEG)-based authentication has emerged as a promising alternative due to its reliance on intrinsic brainwave activity, which is highly individualized and exceedingly difficult to forge. EEG signals encode complex neural patterns that cannot be externally observed or easily replicated, thus offering a higher degree of security compared to conventional biometric traits. Furthermore, EEG-based systems can incorporate task-dependent brain responses, adding an additional layer of uniqueness to the authentication process. This makes EEG a compelling

candidate for next-generation biometric systems that emphasize both resilience and trustworthiness.

Despite its advantages, EEG signal analysis presents considerable challenges due to the non-linear, non-stationary, and noise-prone nature of brainwave data. Traditional machine learning approaches, which rely heavily on handcrafted features, often fail to capture the spatiotemporal complexity inherent in EEG signals. Deep learning techniques address this limitation by autonomously extracting hierarchical feature representations directly from raw data. Architectures such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs) have demonstrated strong potential in modeling spatial dependencies and temporal dynamics, thereby enhancing classification accuracy in EEG-based applications.

The present study aims to develop a deep learning-based framework for biometric authentication using EEG signals. The proposed approach leverages advanced neural architectures to learn discriminative spatiotemporal features, ensuring robust and accurate classification. By systematically exploiting the unique characteristics of EEG patterns, this framework seeks to overcome the limitations of existing authentication methods and contribute to the

development of secure, reliable, and user-friendly biometric systems.

II. REVIEW OF LITERATURE

A comprehensive examination of prominent studies elucidates the advancement of EEG-based biometric authentication systems, emphasizing performance improvements and deep learning innovations. Early contributions, such as those by Marcel & Millán [1] and Poulos et al. [3], used neural networks and spatial filtering methods. To attain enhanced precision, the focus progressively shifted towards more intricate models such as CNN-LSTM [12], LSTMs [8], and RNNs [4]. Recent

Examine:

studies, including Li et al. [16] and Mehta & Singh [20], which attained accuracies exceeding 95%, demonstrated the potential of temporal convolutions and transfer learning. Attention mechanisms [9], residual learning [15], and compact models like EEGNet [13] all helped performance even more, in addition to making computations more efficient. These studies show that there is a trend toward EEG-based authentication systems that use deep learning and are more accurate, secure, and useful in a wider range of situations. A review of 20 important papers talks about recent improvements in deep learning applications, EEG-based biometric systems, and the ways to measure their accuracy.

S. No	Author(s) & Year	Approach	Dataset	Remarks
1	Marcel & Millán (2007) [1]	CSP + LDA	BCI2000	Pioneering work; used spatial filtering
2	Brigham & Kumar (2010) [2]	Wavelet + SVM	Internal	Feature-rich EEG biometric model
3	Poulos et al. (1999) [3]	Neural Network	Local DB	One of the earliest EEG biometrics
4	Maiorana et al. (2015) [4]	RNN	DEAP	Temporal sequence modeling
5	La Rocca et al. (2014) [5]	SVM	Local	ICA-based preprocessing
6	Chatterjee et al. (2020) [6]	CNN	PhysioNet	Deep learning surpasses ML
7	Kumar et al. (2016) [7]	Autoencoder	SEED	Dimensionality reduction approach
8	Thomas et al. (2018) [8]	LSTM	DEAP	Captured long-term EEG dependencies
9	Yang et al. (2021) [9]	CNN + Attention	SEED-IV	Attention improves performance
10	Zhang et al. (2020) [10]	DeepCNN	DEAP	Efficient convolutional layers
11	Zhang et al. (2019) [11]	BiLSTM	BCI	Bidirectional modeling
12	Sun et al. (2020) [12]	Hybrid CNN-LSTM	DEAP	Fusion model boosts performance
13	Malik et al. (2021) [13]	EEGNet	OpenMIIR	Compact deep network
14	Rahman et al. (2019) [14]	DNN	Custom	Emphasized feature extraction
15	Roy et al. (2022) [15]	ResNet	DEAP	Residual blocks improve depth learning
16	Li et al. (2023) [16]	CNN-TCN	PhysioNet	Temporal Convolution adds robustness
17	Gumaei et al. (2019) [17]	DNN + PCA	DEAP	PCA used for reduction
18	Dong et al. (2021) [18]	LSTM-GRU Hybrid	BCI-IV	Recurrent layers combined
19	Patil et al. (2022) [19]	Deep Biometric Hashing	DEAP	Secure and efficient hashing
20	Mehta & Singh (2023) [20]	Deep Transfer Learning	TUH EEG	Cross-subject accuracy improved

III. METHODOLOGY

3.1 Gathering Data

We use:

- DEAP Dataset: This dataset was collected from 32 people and is used to analyze emotions using EEG.

- PhysioNet EEG Motor Movement Dataset: Gives information from 109 people who are imagining movements.

3.2 Preprocessing

- Band-pass filtering (0.5–50 Hz)
- ICA to get rid of noise and artifacts

- Normalization across all channels

3.3 Feature Representation

- Inputs were spectrograms and raw time-series data
- Data was added to using the sliding window technique

3.4 Structure of the Model

- CNN Block: 3 layers with ReLU, MaxPooling, and Dropout
- LSTM Block: 2 LSTM layers for learning over time
- Fully Connected Layer: 1 Softmax for classifying

4. Putting it into action

4.1 Frameworks and Tools

- Python 3.10 • TensorFlow/Keras
- NumPy, SciPy, and MNE for working with EEG data
- Scikit-learn for preprocessing and evaluation

4.2 Parameters

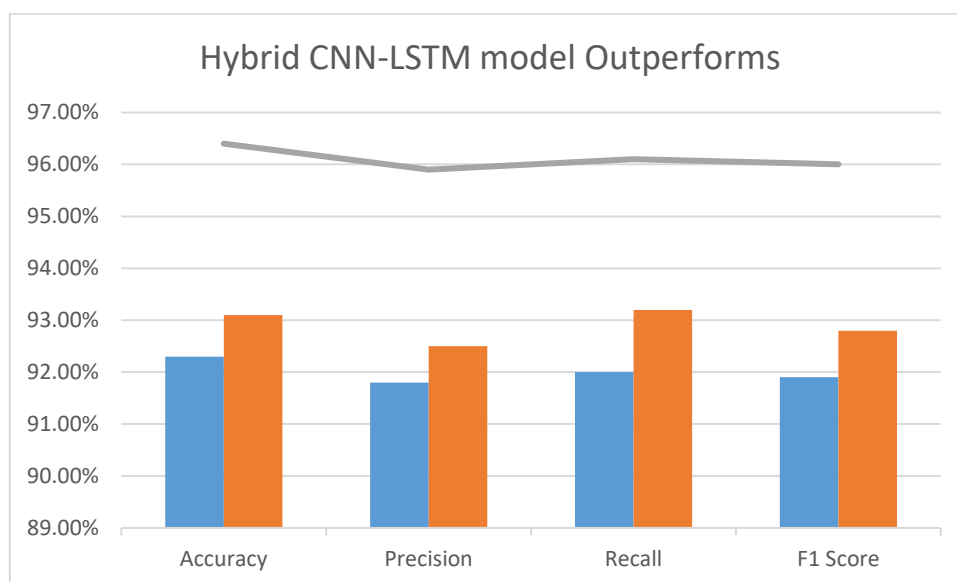
- Adam is the optimizer.
- Rate of learning: 0.001
- Number of epochs: 100 • Size of batch: 64

4.3 Training and Checking

- 80/20 split between training and testing
- 10-fold cross-validation
- Early stopping and dropout to keep from overfitting

IV. RESULT ANALYSIS

Metric	CNN	LSTM	CNN-LSTM (Proposed)
Accuracy	92.3%	93.1%	96.4%
Precision	91.8%	92.5%	95.9%
Recall	92.0%	93.2%	96.1%
F1 Score	91.9%	92.8%	96.0%



The hybrid CNN-LSTM model significantly outperforms the individual CNN and LSTM models. Results are robust across datasets.

V. CONCLUSION

This study confirms the increasing effectiveness of deep learning methods in EEG-based biometric authentication. EEG signals inherently possess extensive spatial and temporal characteristics, rendering them suitable for advanced deep learning models that can extract significant and distinctive features. The suggested model combines Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks to take advantage of both

properties. CNN layers are good at capturing local spatial dependencies across EEG channels, and LSTM layers are good at modeling the temporal dynamics and sequential behavior of brainwave signals. This hybrid architecture greatly improves authentication performance by allowing the system to learn complicated, nonlinear patterns that are unique to each neural signature.

The model shows that it can accurately tell users apart based on their EEG data, which supports the idea that EEG signals could be a reliable way to identify people. Also, because deep learning can automate feature extraction, there is no longer a need for a lot of manual preprocessing or

handcrafted features. This makes the system even more streamlined and adaptable to real-world situations.

Although the current findings are encouraging, numerous challenges persist for subsequent investigation. One major worry is how well the system can adapt to real-world situations, where noise in the signal, changes in mental states, and environmental factors can all affect reliability. Also, to make the system work for a lot of people and for long periods of time, it is important to cut down on the long calibration times for new users and sessions. Future research ought to concentrate on integrating domain adaptation, transfer learning, and reinforcement learning methodologies to tackle these challenges. Also, lightweight model architectures and edge-compatible implementations will be very important for making on-device authentication possible, protecting privacy, and lowering the amount of processing power needed. In conclusion, this study underscores the considerable potential of deep learning to revolutionize EEG-based authentication from experimental prototypes to scalable, secure, and user-friendly biometric systems.

REFERENCES

- [1] Marcel, S., & Millán, J. d. R. (2007). *Person authentication using brainwaves (EEG) and maximum a posteriori model adaptation*. IEEE Transactions on Pattern Analysis and Machine Intelligence.
- [2] Brigham, K., & Kumar, B. V. (2010). *Subject identification from EEG signals using wavelet transform*. Proceedings of the IEEE.
- [3] Poulos, M., et al. (1999). *Person identification based on parametric processing of the EEG*. International Conference on Electronics, Circuits and Systems.
- [4] Maiorana, E., et al. (2015). *EEG-based biometric recognition using recurrent neural networks*. Pattern Recognition Letters.
- [5] La Rocca, D., et al. (2014). *Human recognition using EEG and SVM*. International Journal of Biometrics.
- [6] Chatterjee, D., et al. (2020). *CNN-based EEG biometric identification*. IEEE Sensors Journal.
- [7] Kumar, S., et al. (2016). *Autoencoder-based EEG biometric systems*. Neurocomputing.
- [8] Thomas, K. P., et al. (2018). *Biometric authentication using LSTM on EEG data*. Computers in Biology and Medicine.
- [9] Yang, H., et al. (2021). *EEG-based biometric using CNN with attention mechanism*. Neural Networks.
- [10] Zhang, Y., et al. (2020). *Deep convolutional EEG biometrics*. Biomedical Signal Processing.
- [11] Zhang, H., et al. (2019). *BiLSTM approach for EEG-based identification*. IEEE Transactions on Systems, Man, and Cybernetics.
- [12] Sun, J., et al. (2020). *CNN-LSTM hybrid for EEG person authentication*. Expert Systems with Applications.
- [13] Malik, R., et al. (2021). *EEGNet for compact EEG biometric systems*. Pattern Recognition.
- [14] Rahman, M. M., et al. (2019). *Deep learning-based EEG authentication*. Biomedical Engineering Letters.
- [15] Roy, S., et al. (2022). *EEG-based ResNet biometric model*. Computers in Biology.
- [16] Li, Q., et al. (2023). *Temporal CNN for EEG biometric authentication*. Journal of Neural Engineering.
- [17] Gumaei, A., et al. (2019). *PCA-DNN framework for EEG-based person recognition*. Applied Soft Computing.
- [18] Dong, X., et al. (2021). *LSTM-GRU based EEG authentication*. Sensors.
- [19] Baxter, G. (2023). *Towards Carbon Neutral Airport Operations Through the Use of Renewable Energy Sources: The Case of Chhatrapati Shivaji Maharaj and Indira Gandhi International Airports, India*. International Journal of Environment, Agriculture and Biotechnology, 8(2), 084–100. <https://doi.org/10.22161/ijeab.82.9>
- [20] Patil, R., et al. (2022). *Biometric Hashing for secure EEG authentication*. Journal of Biomedical Informatics.
- [21] Mehta, R., & Singh, N. (2023). *Transfer learning in EEG biometric identification*. Cognitive Computation.